PHOTOGRAPH THIS SHEET

ADA077353

DTIC ACCESSION NUMBER

LEVEL

INVENTORY

Contract No. N00014-70-C-0072

Summary Report, Dtd. 27 Jan. 70

DOCUMENT IDENTIFICATION

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

DISTRIBUTION STATEMENT

ACCESSION FOR		
NTIS GRA&I	X	
DTIC TAB	☐	
UNANNOUNCED	☐	
JUSTIFICATION Per Ltr. on File		
BY		
DISTRIBUTION /		
AVAILABILITY CODES		
DIST	AVAIL AND/OR SPECIAL	
A		

DISTRIBUTION STAMP

DDC
RECEIVED
NOV 27 1979
D

DATE ACCESSIONED

ORIGINAL CONTAINS COLOR PLATES: ALL DDC REPRODUCTIONS WILL BE IN BLACK AND WHITE.

DATE RECEIVED IN DTIC

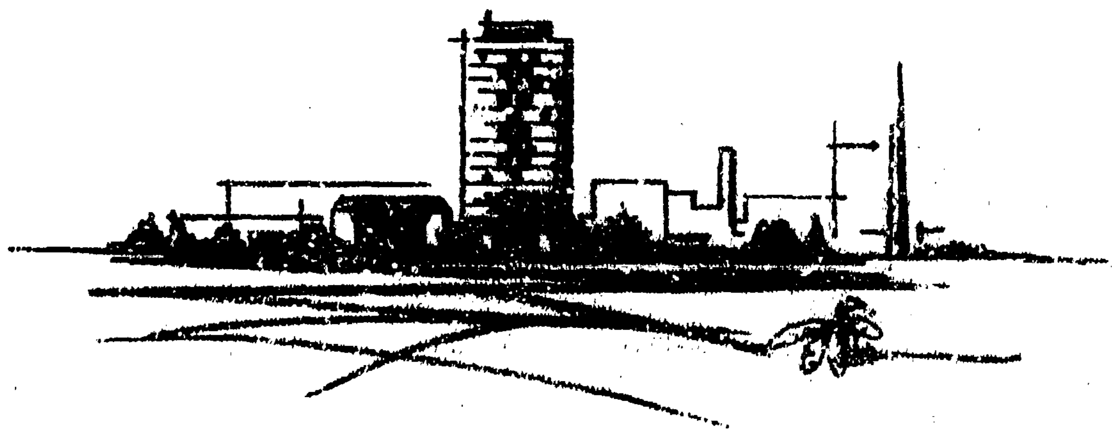
PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDA-2

DTIC FORM OCT 79 70A

DOCUMENT PROCESSING SHEET

5C

RESEARCH REPORT



BATTELLE MEMORIAL INSTITUTE

COLUMBUS LABORATORIES

THE COLUMBUS LABORATORIES of Battelle Memorial Institute comprise the original research center of an international organization devoted to research.

The Institute is frequently described as a "bridge" between science and industry – a role it has performed in more than 90 countries. As an independent research institute, it conducts research encompassing virtually all facets of science and its application. It also undertakes programs in fundamental research and education.

Battelle-Columbus – with its staff of 3,000 – serves industry and government through contract research. It pursues:

- research embracing the physical and life sciences, engineering, and selected social sciences
- design and development of materials, products, processes, and systems
- information analysis, socioeconomic and technical economic studies, and management planning research.

505 KING AVENUE • COLUMBUS, OHIO 43201

SUMMARY REPORT

on

LITER FLOW AND MIX SELECTION IN SEMICLOSED-CIRCUIT SCUBA

to

UNITED STATES NAVY
SUPERVISOR OF DIVING
CONTRACT NO. N00014-70-C-0072

January 27, 1970

by

P. S. Riegel

BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

28 JAN 1970

Battelle Memorial Institute · COLUMBUS LABORATORIES

505 KING AVENUE COLUMBUS, OHIO 43201 · AREA CODE 614, TELEPHONE 299-3151 · CABLE ADDRESS: BATMIN

January 27, 1970

Captain E. B. Mitchell, USN
Supervisor of Diving
Naval Ship Systems Command
Code 00C (D)
Main Navy Building, Room 3023
Washington, D.C. 20360

Dear Captain Mitchell:

We enclose with this letter six copies of our report "Liter Flow and Mix Selection in Semiclosed-Circuit Scuba" and ten enlarged copies of the liter flow selector (Figure 6 in the report).

We believe that use of the liter flow selector will remove much of the mumbo jumbo present in the selection of liter flows today. With the great degree of usage that semi-closed scuba is enjoying, a rational approach to selection of system parameters is necessary and timely.

It has been a great pleasure for us to be able to work on projects as challenging as this one. We invite your questions and comments on the report and look forward to serving you in the future.

Cordially,

D. W. Frink

D. W. Frink
Chief, Equipment Engineering
Division

DWF:nn
Enc.

cc: LCDR. W. I. Milwee, Jr.
CDR. J. H. Boyd
Mr. Denzil Pauli
Lt. Harry Cole
CDR. J. B. Orem

TABLE OF CONTENTS

LITER FLOW AND MIX SELECTION IN SEMICLOSED-CIRCUIT SCUBA

by

P. S. Riegel

INTRODUCTION

The concept of saturation diving has in recent years allowed accomplishment of deep-sea diving work long considered impossible. Use of underwater habitats, pressurized personnel-transfer capsules, deck-decompression chambers, and the like have made it possible for men to descend to great depths, spend some hours working, and return to a relatively comfortable, dry place to rest and live until the next underwater excursion is made.

Besides decompression problems, which have been effectively approached by the various schemes for saturation diving, the problem of gas usage arises. A closed-circuit breathing apparatus is the obvious choice. However, development of closed-circuit deep-diving breathing apparatus is still in its infancy, and today, the most widely used breathing apparatus for saturation diving is the semiclosed-circuit scuba.

The U. S. Navy, with its Mark VI, VIII, and IX semiclosed rigs, has done considerable development and hyperbaric evaluation of equipment, and a variety of semiclosed-circuit breathing apparatus is now being manufactured commercially.

Although it is known that the semiclosed-circuit scuba is an economical rig for deep work, no analysis of the apparatus and its theoretical behavior has been published to date. Flow selection is done by prepared tables, manufacturers' recommendations, and approximate rules of thumb, and has been imperfectly understood by many users.

SUMMARY

This paper presents an analysis of the system, relating all of the variables to one another. Equations are presented to permit calculation of liter flow, mix, oxygen usage, and partial pressure of oxygen.

Finally, and most important, a graphical method is presented which allows rapid selection of proper gas mixture and liter flow. Use of the graphical "Liter Flow and Mix Selector for Semiclosed-Circuit Scuba" should reduce greatly the confusion which presently exists in this field.

DESCRIPTION OF SEMICLOSED SYSTEM

Figure 1 shows schematically a typical semiclosed-circuit breathing system.

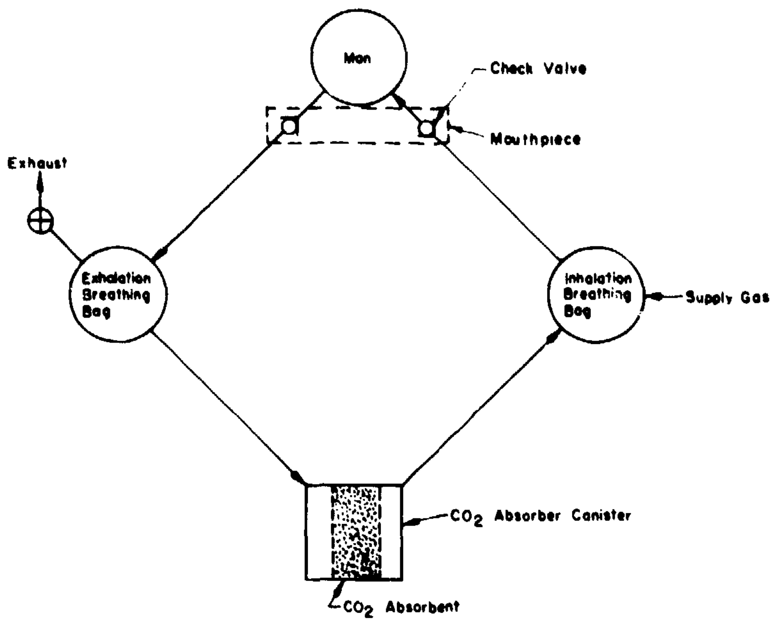


FIGURE 1. SCHEMATIC OF TYPICAL SEMICLOSED-CIRCUIT SCUBA

System Components

The circuit typically contains the following elements:

Mouthpiece. This can be either a jaw-held mouthbit or an oral-nasal mask. The mouthpiece is the interface between the diver and the breathing apparatus.

Check Valves. These are commonly mounted at the mouthpiece, and they are arranged so that the diver will inhale from one hose and exhale into another. By providing for unidirectional flow, it is assured that the diver inhales only pure gas and that no significant amount of his CO_2-laden exhaled gas will be reinhaled.

Hoses. These connect the mouthpiece to the rest of the breathing apparatus with one delivering exhaled gas to the system and the other bringing pure gas to the diver. They are as flexible as possible to allow the diver to move his head freely.

Breathing Bags. These are flexible gas reservoirs that expand to receive exhaled gas and contract to deliver inhaled gas. A rebreather system could not work without

breathing bags, since the breathing apparatus would not be able to store and redeliver the tidal volume of the diver.

Canister. This is a container for a chemical absorbent for CO_2. The diver's exhaled gas is circulated through the canister before it is reinhaled. This removes the CO_2 and makes the exhaled gas suitable for rebreathing.

Gas Supply. As the diver breathes he consumes oxgyen. A gas supply to the system from either backpack bottles or an umbilical hose provides a steady flow of "mixed gas" (oxygen plus a diluent gas) sufficient to replace the oxygen consumed under the severest work conditions. This gas flow is commonly called the "liter flow". The ratio of diluent gas to oxygen is chosen to keep PO_2, the oxygen partial pressure, below a toxic limit.

A common method of regulating the gas flow is to use a sonic-flow orifice to meter gas to the rig. A pressure regulator located upstream from the orifice maintains orifice pressure at a constant level above that necessary to provide critical flow at the maximum depth. Thus, the mass flow rate of the supply gas is invariant.

Exhaust Valve. Since a mixed gas is supplied at a constant rate and since only oxygen is consumed, all diluent gas must escape from the system. An exhaust valve allows gas to vent when a certain system pressure is reached. Since gas is generally supplied at a rate that is far less than the diver's breathing rate, gas escapes only at the end of each exhalation and only in an amount about equal to what was supplied during that particular breathing cycle.

Bypass Valve. As the diver descends, increasing ambient pressure causes gradual collapse of the breathing bags. A bypass valve in the gas supply line usually is provided to allow the diver to keep the apparatus properly inflated as he descends.

ARRANGEMENT OF COMPONENTS

The system shown in Figure 1 is one typical arrangement. It is not necessary to arrange the components precisely as shown. For example, it is not necessary to provide two breathing bags. One bag will do, but when two are provided as shown, flow of gas may proceed through the canister at a lower maximum rate, thus tending to reduce pressure drop and the pulmonary work needed to overcome it.

The exhaust valve generally is located somewhere between the exhalation check valve and the canister. The vented gas then will contain some CO_2, and this choice of exhaust-valve location thus will reduce the amount of CO_2 that the canister must absorb. Also, since peak exhalation pressure normally occurs at the time that the valve is exhausting, breathing effort can be reduced by putting the exhaust valve as close as possible to the mouthpiece to reduce flow losses between mouthpiece and valve.

The gas supply may be brought into the system at any point, but it is obvious that, if gas is brought in between the mouthpiece and the exhaust valve, vented gas will be richer in O_2 than would be the case if only exhaled gas were vented. This would cause unnecessary waste of gas, so the gas usually is supplied to the system at a point downstream from the exhaust valve and upstream from the man.

DERIVATION AND CALCULATIONS

Flow Balances

Inhalation Bag

We will begin the analysis with a flow balance of the inhalation breathing bag. All flows will be given in volumetric units converted to standard temperature and pressure – in the English system, SCFM, in the metric system, SLM. Let us define the supply to the inhalation bag and usage of gas from it by the diver as follows:

Supply gas:

$$O_2 \text{ flow} = L_1$$

$$\text{Total flow} = L = \text{liter flow}$$

Inhaled by man:

$$O_2 \text{ flow} = V_1$$

$$\text{Total flow} = V_2 \quad .$$

Note:

$$V_2 > L \quad .$$

If not, we have an open-circuit free-flow rig.

The remaining flows are calculated by difference, as shown in Figure 2.

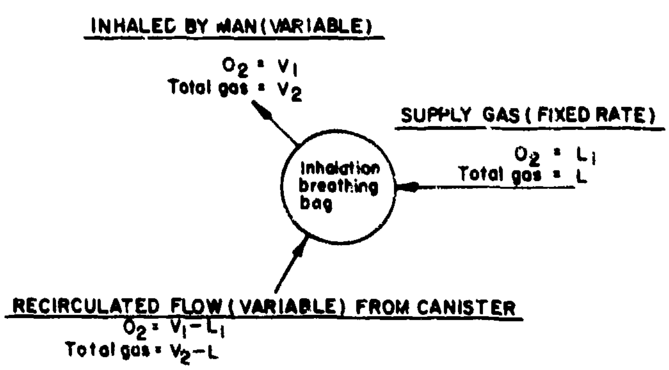


FIGURE 2. INHALATION BREATHING-BAG FLOW BALANCE

Man

The man receives gas from the inhalation bag, absorbs some O_2 from it, and adds some CO_2 to it. Let us define these rates as follows:

$$O_2 \text{ absorbed} = U$$

$$CO_2 \text{ produced} = C \quad .$$

The flows at the diver are as shown in Figure 3.

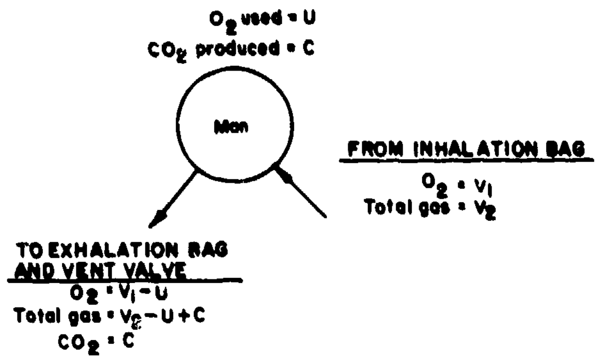


FIGURE 3. MAN FLOW BALANCE

Exhalation Bag

At this point, we have one known flow rate – that from the man – entering the bag. Part of this flow passes on to the CO_2 absorbing canister, and part is exhausted from the system through the vent valve.

Flows to the bag are as follows:

$$O_2 = V_1 - U$$

$$CO_2 = C$$

$$\text{Total} = V_2 - U + C \quad .$$

It is also obvious that

$$\text{Fraction of } O_2 \text{ leaving bag} = \frac{V_1 - U}{V_2 - U + C}$$

$$\text{Fraction of } CO_2 \text{ leaving bag} = \frac{C}{V_2 - U + C} \quad .$$

Since both exiting flows are presently unknown, let us call the exhaust flow "F" for the time being. It then is seen that, for the exhaust flow,

$$\text{Total} = F$$

$$O_2 = F\left[\frac{V_1 - U}{V_2 - U + C}\right].$$

$$CO_2 = F\left[\frac{C}{V_2 - U + C}\right].$$

The remaining flows are found by difference, as shown in Figure 4.

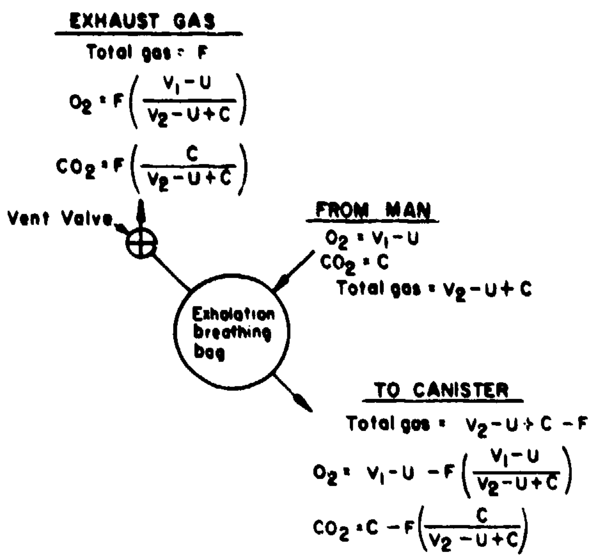


FIGURE 4. EXHALATION BREATHING-BAG FLOW BALANCE

Canister

Since all CO_2 entering the canister is absorbed, a flow balance may be made as shown in Figure 5.

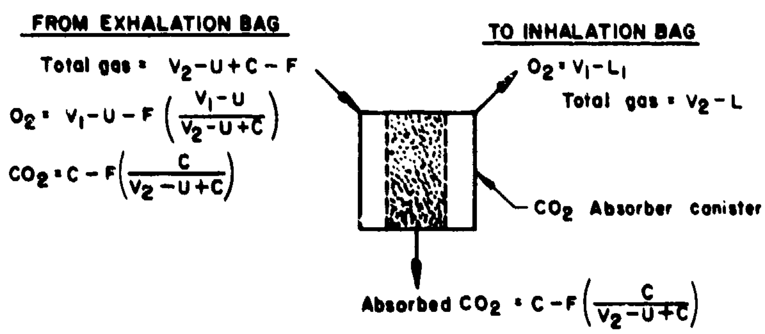


FIGURE 5. CANISTER FLOW BALANCE

Derivation of the Fundamental Equation

From the O_2 balance in Figure 3 it is seen that

$$V_1 - U - F\left(\frac{V_1 - U}{V_2 - U + C}\right) - \left(V_1 - L_1\right) = O$$

or

$$F = \left(\frac{L_1 - U}{V_1 - U}\right)\left(V_2 - U + C\right) . \qquad (1)$$

From the total balance,

$$V_2 - U + C - F - \left[C - F\left(\frac{C}{V_2 - U + C}\right)\right] - \left(V_2 - L\right) = O \quad . \qquad (2)$$

Substitution of (1) in (2) yields, after appropriate manipulation,

$$L\,V_1 - L\,U - UV_1 - L_1 V_2 + L_1 U + UV_2 = O$$

and more rearrangement yields

$$\frac{V_1}{V_2} = \frac{L_1 - U}{L - U} + \frac{U}{V_2}\left(\frac{L - L_1}{L - U}\right) \qquad (3)$$

where $\frac{V_1}{V_2}$ is the volumetric oxygen fraction of the gas breathed by the diver.

Since we normally desire to keep PO_2 within certain limits, an expression relating it to the other variables is of benefit. Now, using more helpful terminology,

D = depth, feet

$A = \frac{D + 33}{33}$ = absolute pressure, atmospheres

$\frac{V_1}{V_2}$ = fraction O_2 in inhalation bag

$\frac{AV_1}{V_2}$ = PO_2 in inhalation bag

P = volume fraction O_2 in liter flow = $\frac{L_1}{L}$

or

$L_1 = LP$.

V_2 is the total volume of gas breathed by the diver per minute. Since the diver's lungs inhale denser gas with increasing depth, V_2 is related to the diver's respiratory minute volume (RMV) by the following relationship:

$$V_2 = A(\text{RMV}).$$

If the new terminology is substituted in (3), the following expression for PO_2 results:

$$PO_2 = A\left[\frac{LP-U}{L-U}\right] + \frac{U}{(RMV)}\left[\frac{L-LP}{L-U}\right], \quad (4)$$

which is the fundamental equation describing the system.

Pulmonary Ventilation and Oxygen Uptake

The value of $\frac{U}{(RMV)}$ must be determined before use can be made of the fundamental equation. The ratio of oxygen consumed to respiratory minute volume has been determined experimentally to have a value of between 1/22 and 1/26, with 1/24 (0.042) a good representative value.[1,3]

Now, let

$$R = \frac{U}{(RMV)} \quad .$$

Equation (4) then may be arranged as follows:

$$PO_2 = A\left(\frac{LP-U}{L-U}\right) + R\left(\frac{L-LP}{L-U}\right), \quad (5)$$

or,

$$L = \frac{U\,(A - PO_2)}{[PA + R(1-P) - PO_2]} \quad (5a)$$

or,

$$P = \frac{UA + PO_2\,(L-U) - RL}{L(A-R)} \quad (5b)$$

or,

$$U = \frac{L\,[PA + R(1-P) - PO_2]}{A - PO_2} \quad . \quad (5c)$$

Use of the Results

The derivation has allowed us to express all of the variables as functions of each other. Any of the arrangements of the fundamental equation may be of help to the user. For diving supervisors, solutions for liter flow and percent oxygen are of value. Medical researchers may find that the oxygen usage of an experimental subject may be determined easily through use of the expressions for U.

One of the most practical uses to which the work has been put was the development of an accurate graphical method of determining the optimum gas mix and flow for dive missions at varying depths.

Graphical Method of Selecting Liter Flow and Oxygen Content

Figure 6 is a curve sheet relating depth and oxygen percentage to liter flow and oxygen partial pressure. It provides a simple and accurate means of selecting liter flow and oxygen percent of breathing gas.

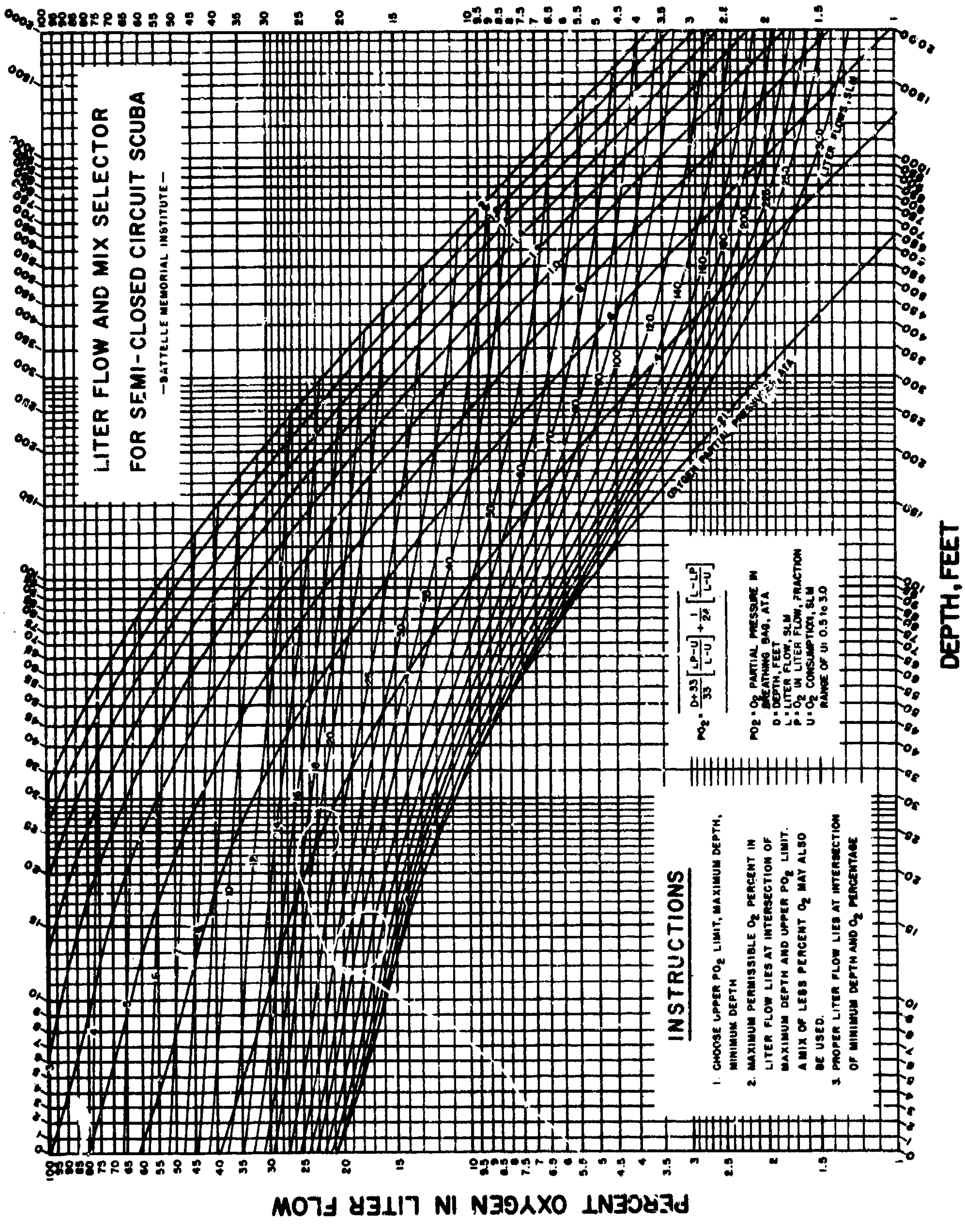

LITER FLOW AND MIX SELECTOR
FOR SEMI-CLOSED CIRCUIT SCUBA
—BATTELLE MEMORIAL INSTITUTE—
INSTRUCTIONS
1. CHOOSE UPPER PO_2 LIMIT, MAXIMUM DEPTH, MINIMUM DEPTH
2. MAXIMUM PERMISSIBLE O_2 PERCENT IN LITER FLOW LIES AT INTERSECTION OF MAXIMUM DEPTH AND UPPER PO_2 LIMIT. A MIX OF LESS PERCENT O_2 MAY ALSO BE USED.
3. PROPER LITER FLOW LIES AT INTERSECTION OF MINIMUM DEPTH AND O_2 PERCENTAGE
$PO_2 = \frac{D+33}{33}\left[\frac{LP-U}{L-U}\right] + \frac{1}{24}\left[\frac{L-LP}{L-U}\right]$
PO_2 = O_2 PARTIAL PRESSURE IN BREATHING BAG, ATA
D = DEPTH, FEET
L = LITER FLOW, SLM
P = O_2 IN LITER FLOW, FRACTION
U = O_2 CONSUMPTION, SLM
RANGE OF U: 0.5 to 3.0
OXYGEN PARTIAL PRESSURE, ATA
LITER FLOW, SLM
PERCENT OXYGEN IN LITER FLOW
DEPTH, FEET

FIGURE 6

To use Figure 6, it is necessary to read on the abscissa at the maximum depth and move vertically until the line of maximum PO_2 desired is encountered. Proper oxygen percentage in the gas mix for the dive then may be read from the oxygen scale at the left. Then move to the left until the minimum depth is reached at the same oxygen percentage, at which point liter flow may be read or interpolated.

Origin of Figure 6

Liter Flow Lines

The properly functioning breathing apparatus will supply gas to the diver at a PO_2 of no less than 0.21 ATA (which is the PO_2 of air at atmospheric pressure) even when the diver's oxygen consumption is at a maximum.

The maximum probable value of oxygen consumption was taken as 3.0 SLM for development of Figure 6. This value is supported by experimental data and by the general experience of users. Although there are surely some unusual individuals who, by heroic effort, can consume in excess of this value in underwater work, it is felt that 3.0 SLM O_2 consumption represents a safe, even conservative, value for oxygen consumption during underwater work.

Liter flow lines were plotted by letting $U = 3$ and $PO_2 = 0.21$. P vs D then was plotted for various values of liter flow, resulting in the family of red liter flow curves shown in Figure 6.

Partial Pressure Lines

The maximum partial pressure in the breathing bag occurs when the diver is at rest. Minimum partial pressure occurs during hard work. A single mixture flowing at a single liter flow must keep PO_2 within acceptable limits at any depth.

Using Equation (5a),

$$L = \frac{U\left(A - PO_2\right)}{\left[PA + R(1-P) - PO_2\right]} , \qquad (5a)$$

U will be maximum and PO_2 minimum for a condition of hard work.
Now, let

Q_1 = inhalation PO_2 at hard work, usually 0.21 ATA (atmospheres absolute)

U_1 = O_2 usage at hard work, usually 3.0 SLM

R = U/(RMV) = 1/24.

Substitution produces, for a condition of hard work,

$$L = \frac{U_1\,(A - Q_1)}{(PA + R(1-P) - Q_1)} . \qquad (5-1)$$

For rest, let

Q_2 = inhalation PO_2 at rest, ATA

U_2 = O_2 usage at rest, usually 0.5 SLM, minimum depth, ATA.

Substitution in Equation (5a) produces, for a condition of rest,

$$L = \frac{U_2\,(A - Q_2)}{(PA + R(1-P) - Q_2)} \quad (5\text{-}2)$$

Both Equations (5-1) and (5-2) relate L, P, and D to each other. Since Figure 6 plots P vs D, elimination of L will be performed by setting Equation (5-1) equal to (5-2) as follows:

$$\frac{U_1\,(A - Q_1)}{PA + R(1-P) - Q_1} = L = \frac{U_2\,(A - Q_2)}{PA + R(1-P) - Q_2} .$$

Elimination of L produces

$$P = \frac{U_1\,(Q_2 - R)(A - Q_1) - U_2\,(Q_1 - R)(A - Q_2)}{(A - R)[U_1\,(A - Q_1) - U_2\,(A - Q_2)]} . \quad (6)$$

Plotting of Equation (6) produces the green PO_2 lines shown, which are based on the following values:

U_1 = 3.0

U_2 = 0.5

Q_1 = 0.21

Q_2 = as indicated

R = 1/24.

Optimum Mixture

The value of P calculated using Equation (6) represents an optimum value from a theoretical point of view, since any greater value of O_2 percent chosen for use will produce too high a maximum PO_2.

A lesser O_2 percent may be used, but only if liter flow is increased as indicated in Figure 6. For any mission, use of the value of P calculated by Equation (6) will result in minimum gas usage.

It is recognized that certain standard mixtures may be available when a dive is planned. A mixture should be chosen that has the highest O_2 content that is still less than the calculated value (P). This will yield a PO_2 that is acceptable and minimize consumption of diluent gas.

Limitations

As is the case with many mathematical expressions, the liter flow formulas may be used to produce erroneous results. To avoid error, the following limitations must be observed:

(1) $\frac{UA}{R} > L > \frac{U}{P}$

This simply states that the total liter flow must be less than the maximum expected RMV of the diver and that it must provide more oxygen than is consumed by the diver.

(2) $AP > PO_2 > R$

When the above limits of L are substituted in Equation (5), these restrictions on PO_2 result. That PO_2 must be less than total oxygen partial pressure is obvious. That it exceeds R is not obvious, but it is true, nonetheless.

(3) $1 > P > \frac{PO_2 - R}{A - R}$

P must of necessity be less than 1. The second part of this restriction is necessary to keep inconsistent values of P from being assumed before calculation begins.

A computer program has been prepared that permits selection of liter flows and mixes within the necessary limitations. It is included in Appendix A of this report.

Figure 6 incorporates these limitations; any O_2 percentage or flow obtained by its use need not be checked for violation of the limitations. However, it must be understood that Figure 6 will allow selection of proper liter flow and mix for only the following conditions:

(1) When the diver is hard at work, his O_2 consumption will be considered to be 3 SLM and his inhalation PO_2 will be 0.21 ATA.

(2) When the diver is resting, his O_2 consumption will be 0.5 SLM and his inhalation PO_2 will be as indicated by the green lines.

Selection of Mix and Liter Flow

Calculation Method

(1) Establish values for the following:

(a) Maximum O_2 usage, SLM = U_1

(b) Minimum O_2 usage, SLM = U_2

(c) Maximum PO_2 level, ATA = Q_2

(d) Minimum PO_2 level, ATA = Q_1

(e) Maximum depth, feet = D_1

(f) Minimum depth, feet = D_2

(2) Let $A_1 = \frac{D_1+33}{33}$ = maximum depth in atmospheres absolute

$A_2 = \frac{D_2+33}{33}$ = minimum depth in atmospheres absolute

(3) Calculate maximum fraction O_2 as follows:

$$P_{max} = \frac{U_1\,(Q_2 - 0.042)\,(A_1 - Q_1) - U_2\,(Q_1 - 0.042)(A_1 - Q_2)}{(A_1 - 0.042)\,[U_1\,(A_1 - Q_1) - U_2\,(A_1 - Q_2)]}$$

(4) Calculate minimum allowable fraction O_2 as follows:

$$P_{min} = Q_1/A_2$$

(5) Select a mix from what is available, so long as the selected mix lies in the range defined in Steps (3) and (4). Use the highest available mix in the range.

Let mixture O_2 fraction = P_{mix}

(6) Calculate liter flow as follows:

$$L = \frac{U_1\,(A_2 - Q_1)}{[P_{mix}\,A_2 + 0.042\,(1 - P_{mix}) - Q_1]}\,.$$

<u>Chart Method</u>

Figure 6 was drawn based on the following:

Maximum O_2 usage, U_1 = 3.0 SLM

Minimum O_2 usage, U_2 = 0.5 SLM

Minimum PO_2 level, Q_1 = 0.21

To use Figure 6, proceed as follows:

(1) Establish values for

(a) Maximum PO_2 level, ATA = Q_2

(b) Maximum depth, feet = D_1

(c) Minimum depth, feet = D_2

(2) Locate maximum percent O_2 at intersection of maximum depth line and maximum PO_2 line

(3) Locate minimum percent O_2 at intersection of minimum depth line and 0.21 PO_2 line

(4) Select a mix from what is available, so long as it lies in the range between P_{min} and P_{max}. The most economy will result if P_{mix} is near but just less than P_{max}.

(5) Locate correct liter flow at intersection of P_{mix} line and minimum depth line.

Example Problems

In all of the problems, the following is assumed:

PO_2 minimum, $Q_1 = 0.21$ ATA

Maximum O_2 usage, $U_1 = 3.0$ SLM

Minimum O_2 usage, $U_2 = 0.5$ SLM.

Available mixtures have the following oxygen percentages: 4, 6, 8, 10, 12, 15, 20, 25, 30, 40, 50, and 60.

Example 1 – Dive from Surface

A diver must descend from the surface to a depth of 125 feet, perform a task, and reascend. The mission is of such duration that a PO_2 of 1.6 ATA must not be exceeded. What mix should be used and what should be the liter flow?

Solution by calculation:

(1) Given: $U_1 = 3.0$

$U_2 = 0.5$

$Q_1 = 0.21$

$Q_2 = 1.60$

$D_1 = 125$

$D_2 = 0$

(2) $A_1 = \dfrac{125 + 33}{33} = 4.79$

$A_2 = \dfrac{0 + 33}{33} = 1$

(3) $$P_{max} = \frac{3\,(1.60 - 0.042)(4.79 - 0.21) - 0.5\,(0.21 - 0.042)(4.79 - 1.60)}{(4.79 - 0.042)[3.0\,(4.79 - 0.21) - 0.5\,(4.79 - 1.60)]}$$

$= 0.367 \doteq 36.7$ percent

(4) $P_{min} = \dfrac{0.21}{1} = 0.21 = 21$ percent

(5) Either 25 percent or 30 percent can be used. Use 30 percent since it is more economical.

(6) $$L = \frac{3.0\,(1 - 0.21)}{[0.30(1) + 0.042\,(1 - 0.30) - 0.21]}$$

$$= 19.9 \text{ SLM}$$

Thus, a 30 percent O_2 mix should be used at a flow of 20 SLM.

Solution by graph (Figure 6):

(1) Maximum PO_2 level = 1.6 ATA

Maximum depth = 125 feet

Minimum depth = 0 feet

(2) Maximum percent O_2 = 37 percent (at intersection of D = 125 and PO_2 = 1.6)

(3) Minimum percent O_2 = 21 percent (at intersection of D = O and PO_2 = 0.21)

(4) Use 30 percent mix.

(5) Liter flow = 20 SLM (at intersection of 30 percent O_2 and D = O)

Note: If we had chosen to use a 25 percent O_2 mix, liter flow would be 33 SLM.

<u>Example 2 - Dive from PTC</u>

Divers will descend in a PTC to a depth of 450 feet. They will not swim above the 450-foot level, but may descend to the 820-foot level. PO_2 is limited to 1.3 ATA. What should be the mix and flow?

Solution by calculation:

(1) Given: $U_1 = 3.0$

$U_2 = 0.5$

$Q_1 = 0.21$

$Q_2 = 1.3$

$D_1 = 820$

$D_2 = 450$

(2) $A_1 = \dfrac{820 + 33}{33} = 25.8$ ATA

$A_2 = \dfrac{450 + 33}{33} = 14.6$ ATA

(3) $P_{max} = \dfrac{3\,(0.5 - 0.042)(25.8 - 0.21) - 0.5\,(0.21 - 0.042)(25.8 - 1.3)}{(25.8 - 0.042)[3\,(25.8 - 0.21) - 0.5\,(25.8 - 1.3)]}$

$= 0.0568 = 5.68$ percent

(4) $P_{min} = \dfrac{0.21}{14.6} = 0.0144 = 1.44$ percent

(5) $P_{mix} = 4$ percent

This is the only available mix that lies within the acceptable range.

(6) $L = \dfrac{3\,(14.6 - 0.21)}{[0.04\,(14.6) + 0.042\,(1 - 0.04) - 0.21]}$

$= 104.2$ SLM

Solution by graph (Figure 6):

(1) Maximum PO_2 level = 1.3 ATA

Maximum depth = 820 feet

Minimum depth = 450 feet

(2) Maximum percent O_2 = 5.6 percent (at intersection of D = 820 and PO_2 = 1.3)

(3) Minimum percent O_2 = 1.42 (at intersection of D = 450 and PO_2 = 0.21)

(4) Use 4 percent O_2

This is the only available mix in the range.

(5) Liter flow = 106 SLM (at intersection of D = 450 and percent O_2 = 4 percent)

Example 3 - Chamber Dive

A simulated saturation dive is being conducted in a pressure chamber. Depth is 600 feet. Maximum allowable PO_2 is 1.2 ATA. A gas mixer is available to produce any desired mix. What mix and flow should be used?

Solution by Calculations

(1) Given: $U_1 = 3.0$

$U_2 = 0.5$

$Q_1 = 0.21$

$Q_2 = 1.2$

$D_1 = D_2 = 600$

(2) $A_1 = A_2 = \frac{600 + 33}{33} = 19.2$ ATA

(3) $$P_{max} = \frac{3\,(1.2 - 0.042)(19.2 - 0.21) - 0.5\,(0.21 - 0.042)(19.2 - 1.2)}{(19.2 - 0.042)[3\,(19.2 - 0.21) - 0.5\,(19.2 - 1.2)]}$$

$= 0.0702 = 7.02$ percent

(4) $P_{min} = \frac{0.21}{19.2} = 0.0109 = 1.09$ percent

(5) Since we have a gas mixer, we will use $P_{mix} = P_{max} = 7.0$ percent.

(6) $$L = \frac{3\,(19.2 - .21)}{[.07(19.2) + .042\,(1 - .07) - .21]}$$

$L = 48.6$ SLM

Solution by graph:

(1) Maximum PO_2 level = 1.2 ATA

Maximum depth = 600 feet

Minimum depth = 600 feet

(2) Maximum percent O_2 = 7.0 percent (at intersection of D = 600 and PO_2 = 1.2)

(3) Minimum percent O_2 = 1.15 percent (at intersection D = 600 and PO_2 = 0.21)

(4) Use 7.0 percent, since we have a gas mixer.

(5) Liter flow = 49 SLM (at intersection of D = 627 and percent O_2 = 6.7 percent)

Miscellaneous Calculations

Example 4 - O_2 Usage in Chamber Dive

In the saturation dive of Example 3, a 4 percent O_2 - 96 percent He mix is being used at a flow of 96 SLM. A subject wearing a semiclosed-circuit rig is exercising in the wet pot. A flexible hose removes samples of gas from his inhalation bag for analysis. At one time, it is observed that his inhalation O_2 percentage is 2.0. What is his rate of O_2 consumption?

Solution: From Equation (5c),

$$U = \frac{L\left[PA - PO_2 + R\,(1-P)\right]}{A - PO_2}$$

From Example 3, A = 19.2 ATA

Inhalation $PO_2 = 0.02\ (19.2) = 0.384$ ATA

Substituting in Equation (5c) above,

$$U = \frac{96\left[0.04\ (19.2) - 0.384 + \frac{1}{24}\ (1 - 0.04)\right]}{19.2 - 0.384}$$

$$U = 2.16 \text{ SLM}$$

Example 5 - PO_2 Determination in Chamber Dive

If the diver in Example 4 was resting and consuming O_2 at a rate of 0.5 SLM, what would be the PO_2 in his inhalation bag?

Solution: From Equation (5),

$$PO_2 = A\left(\frac{LP-U}{L-U}\right) + R\left(\frac{L-LP}{L-U}\right)$$

From Example 4, A = 19.2 ATA

Substituting,

$$PO_2 = 19.2\left[\frac{96(0.04) - 0.5}{96 - 0.5}\right] + \frac{1}{24}\left[\frac{96 - 96(0.04)}{96 - 0.5}\right]$$

$$= 0.711 \text{ ATA} \ .$$

ACKNOWLEDGMENTS

The author expresses his gratitude to the Office of the Supervisor of Diving for funding this effort; to Mr. Herbert R. Hazard for technical consultation; and to Messrs. Patrick Afamefuna Morris, Leslie F. Nikodem, and William R. Dick for assistance in the development and preparation of Figure 6.

REFERENCES

(1) United States Navy Diving Manual, Navships 250-538, July, 1963.

(2) Diving Technics, Gerhard Haux, Dragerwerk, Lubeck, Western Germany, 1968.

(3) "Pulmonary Ventilation and Effect of Oxgyen Breathing in Heavy Exercise", Erling Asmussen and Marius Nielsen, Acta Physiol. Scand., 1958, 43, 365-378.

(4) U. S. Navy Diving - Gas Manual, Research Report Number 3-69, U. S. Navy Supervisor of Diving, Naval Ship Systems Command, October 1, 1969.

APPENDIX A

COMPUTER PROGRAM FOR LITER FLOW AND MIX SELECTION

The program incorporates the limitations of the method and will not give a final answer until all data are presented properly.

The program is followed by printouts of sample problems showing the debugging process as it confronts the user.

LITERS   14:26   CY TUE 01/13/70

```
100 PRINT "THIS PROGRAM CALCULATES THE PROPER GAS MIXTURES AND FLOWS"
110 PRINT "FOR SEMI-CLOSED CIRCUIT SCUBA. TO USE IT, JUST ANSWER"
120 PRINT "THE QUESTIONS AS THEY APPEAR."
130 PRINT
140 PRINT
150 PRINT "MAXIMUM O2 USAGE, SLM =";
160 INPUT U3
170 PRINT "MINIMUM O2 USAGE, SLM =";
180 INPUT U4
190 IF U4>U3 THEN 210
200 GO TO 250
210 PRINT
220 PRINT "ENTRY MISTAKE. TRY AGAIN"
230 PRINT
240 GO TO 150
250 PRINT "MAXIMUM DEPTH, FEET =";
260 INPUT D1
270 PRINT "MINIMUM DEPTH, FEET =";
280 INPUT D2
290 IF D2>D1 THEN 310
300 GO TO 350
310 PRINT
320 PRINT "ENTRY ERROR. TRY AGAIN."
330 PRINT
340 GO TO 250
350 LET A1=(D1+33)/33
360 LET A2=(D2+33)/33
370 PRINT "MAXIMUM PO2 LEVEL, ATA =";
380 INPUT O4
390 LET R=1/24
400 IF O4<R THEN 470
410 IF O4>A1 THEN 510
420 PRINT "MINIMUM PO2 LEVEL, ATA =";
430 INPUT O3
440 IF O3<R THEN 470
450 IF O3>A1 THEN 510
460 GO TO 550
470 PRINT
480 PRINT "PO2 LEVEL MAY NOT BE LESS THAN 1/24. TRY AGAIN"
490 PRINT
500 GO TO 370
510 PRINT
520 PRINT "PO2 CANNOT EXCEED",A1,"TRY AGAIN"
530 PRINT
540 GO TO 370
550 IF O3>O4 THEN 570
560 GO TO 610
570 PRINT
580 PRINT "ENTRY MISTAKE. TRY AGAIN"
590 PRINT
600 GO TO 370
610 PRINT
620 LET X=U3*(O4-R)*(A1-O3)-U4*(O3-R)*(A1-O4)
630 LET Y=(A1-R)*(U3*(A1-O3)-U4*(A1-O4))
640 LET P3=X/Y
650 LET Z=O3/A2
660 IF Z>P3 THEN 710
670 PRINT
680 PRINT "MAXIMUM ALLOWABLE PERCENT O2 =",100*P3
690 PRINT"MINIMUM ALLOWABLE PERCENT O2 =",100*Z
700 GO TO 740
710 PRINT "DEPTH RANGE TOO EXTREME FOR SPECIFIED PO2 RANGE."
720 PRINT "EXPAND THE PO2 RANGE OR NARROW THE DEPTH RANGE."
730 GO TO 250
740 PRINT
750 PRINT "WHAT PERCENT O2 DO YOU WISH TO USE?";
760 GO TO 800
770 PRINT
780 PRINT "IF YOU WISH TO TRY ANOTHER PERCENT O2, TYPE IT WHEN"
790  PRINT "THE QUESTION APPEARS. IF NOT, TYPE '101'"
800 INPUT P1
810 PRINT
820 LET P=P1/100
830 IF P1=101 THEN 940
840 IF P3<P THEN 900
850 IF Z>P THEN 920
860 LET L=U3*(A2-O3)/(A2*P+R*(1-P)-O3)
870 PRINT
880 PRINT "LITER FLOW =",L,"SLM"
890 GO TO 770
900 PRINT "YOUR O2 CONTENT IS TOO HIGH. CHOOSE A LOWER VALUE."
910 GO TO 750
920 PRINT "YOUR O2 CONTENT IS TOO LOW. CHOOSE A HIGHER VALUE."
930 GO TO 750
940 END
```

```
LITERS    14:22   CY TUE 01/13/70

THIS PROGRAM CALCULATES THE PROPER GAS MIXTURES AND FLOWS
FOR SEMI-CLOSED CIRCUIT SCUBA. TO USE IT, JUST ANSWER
THE QUESTIONS AS THEY APPEAR.

MAXIMUM O2 USAGE, SLM =? 3.0
MINIMUM O2 USAGE, SLM =? 0.5
MAXIMUM DEPTH, FEET =? 900
MINIMUM DEPTH, FEET =? 600
MAXIMUM PO2 LEVEL, ATA =? 1.4
MINIMUM PO2 LEVEL, ATA =? .21

MAXIMUM ALLOWABLE PERCENT O2 = 5.61199
MINIMUM ALLOWABLE PERCENT O2 = 1.09479

WHAT PERCENT O2 DO YOU WISH TO USE?? 5.0

LITER FLOW =     72.166        SLM

IF YOU WISH TO TRY ANOTHER PERCENT O2, TYPE IT WHEN
THE QUESTION APPEARS. IF NOT, TYPE '101'
? 4.0

LITER FLOW =     95.2922       SLM

IF YOU WISH TO TRY ANOTHER PERCENT O2, TYPE IT WHEN
THE QUESTION APPEARS. IF NOT, TYPE '101'
? 5.61199

LITER FLOW =     62.8338       SLM

IF YOU WISH TO TRY ANOTHER PERCENT O2, TYPE IT WHEN
THE QUESTION APPEARS. IF NOT, TYPE '101'
? 101



USED    24.67 UNITS
```

```
LITERS    14:14   CY TUE 01/13/70

THIS PROGRAM CALCULATES THE PROPER GAS MIXTURES AND FLOWS
FOR SEMI-CLOSED CIRCUIT SCUBA. TO USE IT, JUST ANSWER
THE QUESTIONS AS THEY APPEAR.


MAXIMUM O2 USAGE, SLM =? 0.5
MINIMUM O2 USAGE, SLM =? 3.0

ENTRY MISTAKE, TRY AGAIN

MAXIMUM O2 USAGE, SLM =? 3.0
MINIMUM O2 USAGE, SLM =? 0.5
MAXIMUM DEPTH, FEET =? 600
MINIMUM DEPTH, FEET =? 900

ENTRY ERROR. TRY AGAIN.

MAXIMUM DEPTH, FEET =? 900
MINIMUM DEPTH, FEET =? 600
MAXIMUM PO2 LEVEL, ATA =? .21
MINIMUM PO2 LEVEL, ATA =? 1.4

ENTRY MISTAKE. TRY AGAIN

MAXIMUM PO2 LEVEL, ATA =? 1.4
MINIMUM PO2 LEVEL, ATA =? .021

PO2 LEVEL MAY NOT BE LESS THAN 1/24. TRY AGAIN

MAXIMUM PO2 LEVEL, ATA =? 140

PO2 CANNOT EXCEED              28.2727       TRY AGAIN

MAXIMUM PO2 LEVEL, ATA =? 1.4
MINIMUM PO2 LEVEL, ATA =? 1.0

DEPTH RANGE TOO EXTREME FOR SPECIFIED PO2 RANGE.
EXPAND THE PO2 RANGE OR NARROW THE DEPTH RANGE.
MAXIMUM DEPTH, FEET =? 900
MINIMUM DEPTH, FEET =? 600
MAXIMUM PO2 LEVEL, ATA =? 1.4
MINIMUM PO2 LEVEL, ATA =? .21


MAXIMUM ALLOWABLE PERCENT O2 = 5.61199
MINIMUM ALLOWABLE PERCENT O2 = 1.09479

WHAT PERCENT O2 DO YOU WISH TO USE?? 6.0

YOUR O2 CONTENT IS TOO HIGH. CHOOSE A LOWER VALUE.
WHAT PERCENT O2 DO YOU WISH TO USE?? 1.0

YOUR O2 CONTENT IS TOO LOW. CHOOSE A HIGHER VALUE.
WHAT PERCENT O2 DO YOU WISH TO USE?? 5.0


LITER FLOW =    72.166        SLM

IF YOU WISH TO TRY ANOTHER PERCENT O2, TYPE IT WHEN
THE QUESTION APPEARS. IF NOT, TYPE '101'
? 4.0


LITER FLOW =    95.2922       SLM

IF YOU WISH TO TRY ANOTHER PERCENT O2, TYPE IT WHEN
THE QUESTION APPEARS. IF NOT, TYPE '101'
? 101



USED    49.67 UNITS
```

APPENDIX B

MISCELLANEOUS COMPUTER PROGRAMS DEVELOPED DURING THE COURSE OF THE WORK

DEPTHS

This program was used to plot points for the liter flow guide.

LITRES

This program calculates liter flow and mix for various depth conditions. It does not incorporate all of the limitations of the method.

FIGPO2

This program computes PO_2.

PETE08

This program computes liter flow by the new method and by one old method and illustrates that significant gas may be saved through use of the new method.

```
DEPTHS     14:32    CY TUE 01/13/70

100 LET L=300
110PRINT"","LITER FLOW =",L,"SLM"
120 PRINT
130 PRINT
140PRINT"","UPPER TOXIC LIMITS FOR U=0.5 SLM"
150LET R=2.5/60
160PRINT"","DEPTH","PERCENT O2","PO2"
170 LET DO=((33*L)/72)-33
180 LET P3=(3300*.21)/(DO+33)
190 GO TO 200
200 PRINT "",DO,P3,".21"
210 FOR P1=.4 TO 2.01 STEP .2
220 LET J=DO
230 LET N=1000
240 FOR D=J TO 10000 STEP N
250 LET A=(D+33)/33
260LET P=100*(3*A+.21*(L-3)-R*L)/(L*(A-R))
270 LET T=100*(.5*A+P1*(L-.5)-R*L)/(L*(A-R))
280 LET X=P/T
290 IF X>=1 THEN310
300 NEXT D
310 LET J=D-N
320 LET N=N/10
330 IF N<=1E-3 THEN 350
340 GO TO 240
350 PRINT"",D,P,P1
360 NEXT P1
370 PRINT
380 PRINT
390PRINT"","DEPTH VS PERCENT O2 FOR U=3 SLM, PO2=.21 ATA"
400 PRINT "","DEPTH","PERCENT O2"
410 READ D
420 LET A=(D+33)/33
430 LET P=100*(3*A+.21*(L-3)-R*L)/(L*(A-R))
440 LET T=100*(.5*A+2*(L-.5)-R*L)/(L*(A-R))
450 LET X=P/T
460 IF D<=DO THEN 410
470 PRINT "",D,P
480 IF X>=1 THEN 530
490 GO TO 410
500DATA0,1,2,3,4,5,6,7,8,9,10,12,14,16,18,20,25,30,35,40,50,60,70
510 DATA 80,90,100,120,140,160,180,200,300,400,500,600,700,800,
520 DATA900,1000,1200,1400,1600,1800,2000
530 END
```

DEPTHS 14:35 CY TUE 01/13/70

LITER FLØW = 300 SLM

UPPER TØXIC LIMITS FØR U=0.5 SLM

DEPTH	PERCENT Ø2	PØ2
104.5	5.04	.21
725.08	1.72676	.4
1515.76	1.3554	.6
2306.44	1.23521	.8
3097.12	1.17577	1.
3887.8	1.14031	1.2
4678.48	1.11676	1.4
5469.1(	1.09998	1.6
6259.84	1.08741	1.8
7050.52	1.07765	2.

DEPTH VS PERCENT Ø2 FØR U=3 SLM, PØ2=.21 ATA

DEPTH	PERCENT Ø2
120	4.62701
140	4.20434
160	3.8699
180	3.59868
200	3.37429
300	2.65833
400	2.27413
500	2.03446
600	1.87068
700	1.75168
800	1.66129
900	1.59031
1000	1.53309
1200	1.44652
1400	1.38414
1600	1.33705
1800	1.30025
2000	1.27069

ØUT ØF DATA IN 410

USED 4.17 UNITS

```
LITRES    14:38   CY TUE 01/13/70

100 READ D1,D2,O2
110 LET U1=3
120 LET U2=.5
130 LET A1=(D1+33)/33
140 LET A2=(D2+33)/33
150 LET O1=.21
160 LET R=1/24
170 LET X=U2*(A1-O2)*(O1-R)-U1*(O2-R)*(A1-O1)
180 LET Y=(A1-R)*(U2*(A1-O2)-U1*(A1-O1))
190 LET P=X/Y
200 LET P1=100*P
210 LET L=(U1*(O1-A2))/(O1-R*(1-P)-P*A2)
220 PRINT "MAXIMUM DEPTH,FT =",D1
230 PRINT "MINIMUM DEPTH,FT =",D2
240 PRINT "MAXIMUM INHALATION PO2,ATA =",O2
250 PRINT "MAXIMUM O2 CONSUMPTION,SLM =",U1
260 PRINT "MINIMUM O2 CONSUMPTION,SLM =",U2
270 PRINT "MAXIMUM PERCENT O2 =",P1
280 PRINT "LITER FLOW,SLM =",L
290 DATA 625,300,1.4
300 END



RUN



LITRES    14:39   CY TUE 01/13/70

MAXIMUM DEPTH,FT =               625
MINIMUM DEPTH,FT =               300
MAXIMUM INHALATION PO2,ATA =     1.4
MAXIMUM O2 CONSUMPTION,SLM =     3
MINIMUM O2 CONSUMPTION,SLM =     .5
MAXIMUM PERCENT O2 =             7.93715
LITZR FLOW,SLM =                 47.105



USED     2.17 UNITS
```

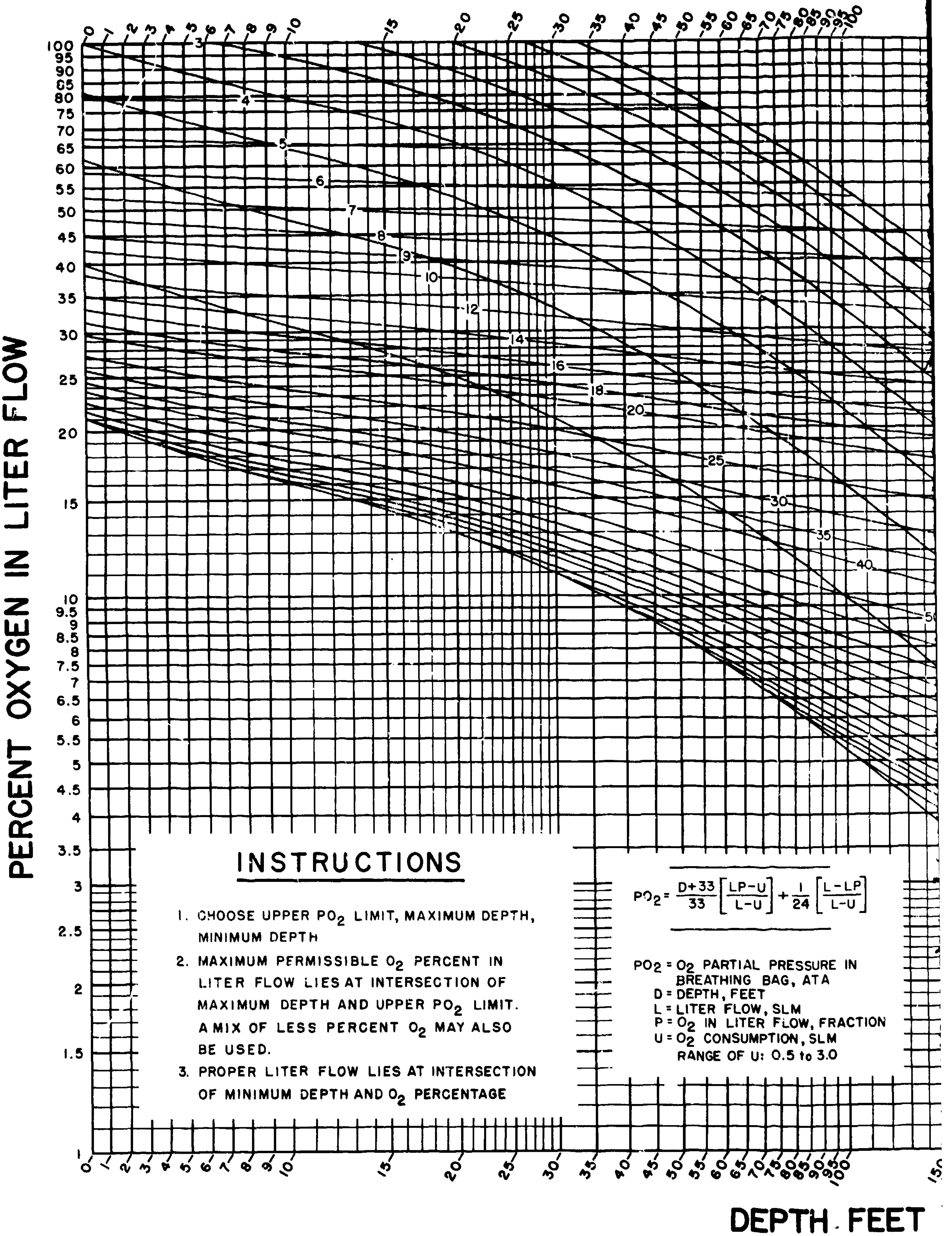
```
FIGPO2     14:41     CY  TUE  01/13/70

100 PRINT "DEPTH","PERCENT O2","LITER FLOW","O2 USAGE","PO2"
110 PRINT
120 READ D,P,L,U
130 LET A=(D+33)/33
140 LET R=1/24
150 LET Q=A*((L*P-U)/(L-U))+R*((L-L*P)/(L-U))
160 PRINT D,100*P,L,U,Q
170 GO TO 120
180 DATA 500,.06,60,.5
190 DATA 800,.06,60,.5
200 END



RUN



FIGPO2     14:42     CY  TUE  01/13/70

DEPTH          PERCENT O2     LITER FLOW     O2 USAGE       PO2

 500           6.             60             .5             .881003
 800           6.             60             .5             1.35465

OUT OF DATA  IN 120



USED      1.83 UNITS
```

```
PETEOS     14:43    CY  TUE 01/13/70

100 LET Q2=1.2
110 PRINT "LITER FLOW AT OPTIMUM PERCENT O2 FOR PO2 =",Q2,"ATA"
120 PRINT
130 PRINT "DEPTH","SLM,NEW","SLM,OLD","ERROR"
140 READ D
150 LET A=(D+33)/33
160 LET B=(Q2-A)/(.21-A)
170 LET U2=.5
180 LET R=1/24
190 LET U1=3
200 LET Q1=.21
210 LET P=(U2*B*(Q1-R)-U1*(Q2-R))/((A-R)*(U2*B-U1))
220 LET Q3=100*(Q2/A)
230 LET P2=100*(P/Q3)
240 LET P1=100*P
250 LET P3=Q2/A
260 LET L1=(U1*(Q1-A))/(Q1-R*(1-P)-P*A)
270 LET L2=(U1*(Q1-A))/(Q1-P3*A)
280 LET T=100*((L2-L1)/L1)
290 PRINT D,L1,L2,T
300 GO TO 140
310 DATA 0,10,20,30,50,70,100,200,300,500,700,1000,2000
320 END
```

```
PETEOS     14:45    CY  TUE 01/13/70

LITER FLOW AT OPTIMUM PERCENT O2 FOR PO2 =     1.2          ATA
```

DEPTH	SLM,NEW	SLM,OLD	ERROR
0	2.49493	2.39394	-4.04858
10	3.26018	3.31221	1.59609
20	4.02541	4.23049	5.09467
30	4.79063	5.14876	7.47556
50	6.32109	6.98531	10.508
70	7.85155	8.82185	12.3582
100	10.1472	11.5767	14.0871
200	17.7995	20.7594	16.6291
300	25.4518	29.9[illegible]21	17.6426
500	40.7564	48.30[illegible]6	18.5278
700	56.0609	66.6731	18.9297
1000	79.0178	94.2213	19.2407
2000	155.541	186.049	19.6142

```
OUT OF DATA  IN 140



USED      2.67 UNITS
```

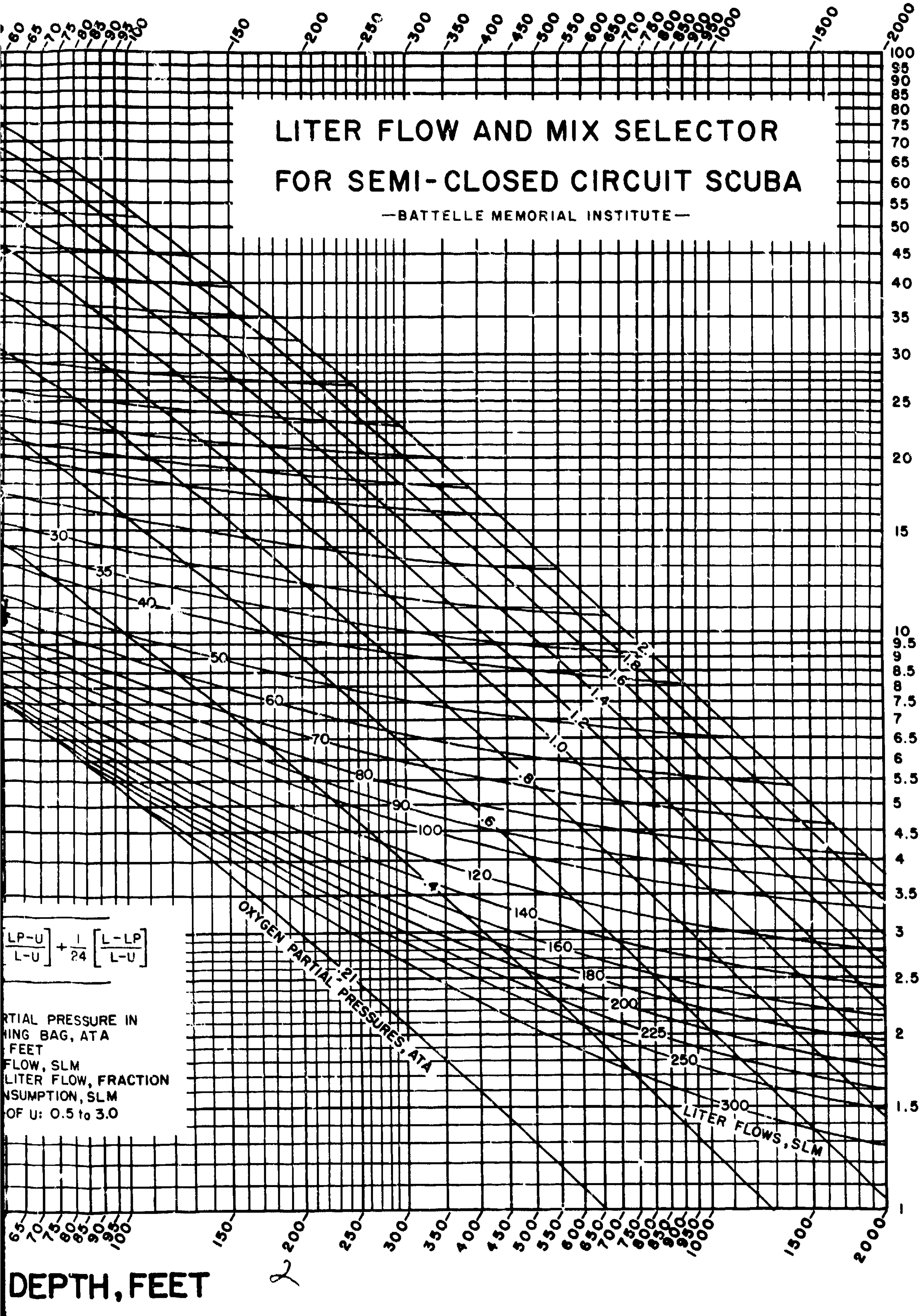


INSTRUCTIONS

1. CHOOSE UPPER PO_2 LIMIT, MAXIMUM DEPTH, MINIMUM DEPTH
2. MAXIMUM PERMISSIBLE O_2 PERCENT IN LITER FLOW LIES AT INTERSECTION OF MAXIMUM DEPTH AND UPPER PO_2 LIMIT. A MIX OF LESS PERCENT O_2 MAY ALSO BE USED.
3. PROPER LITER FLOW LIES AT INTERSECTION OF MINIMUM DEPTH AND O_2 PERCENTAGE

$$PO_2 = \frac{D+33}{33}\left[\frac{LP-U}{L-U}\right] + \frac{1}{24}\left[\frac{L-LP}{L-U}\right]$$

PO_2 = O_2 PARTIAL PRESSURE IN BREATHING BAG, ATA
D = DEPTH, FEET
L = LITER FLOW, SLM
P = O_2 IN LITER FLOW, FRACTION
U = O_2 CONSUMPTION, SLM
RANGE OF U: 0.5 to 3.0


LITER FLOW AND MIX SELECTOR
FOR SEMI-CLOSED CIRCUIT SCUBA
—BATTELLE MEMORIAL INSTITUTE—
60 65 70 75 80 85 90 95 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000 1500 2000
100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 9.5 9 8.5 8 7.5 7 6.5 6 5.5 5 4.5 4 3.5 3 2.5 2 1.5 1
30 35 40 50 60 70 80 90 100 120 140 160 180 200 225 250 300
LITER FLOWS, SLM
2.2 1.8 1.6 1.4 1.2 1.0 .8 .6 .4 .21
OXYGEN PARTIAL PRESSURES, ATA
LP-U / L-U + 1/24 [L-LP / L-U]
RTIAL PRESSURE IN
HING BAG, ATA
FEET
FLOW, SLM
LITER FLOW, FRACTION
NSUMPTION, SLM
OF U: 0.5 to 3.0
DEPTH, FEET